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# User Assessment of Smoke-Dispersion Models for Wildland Biomass Burning

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**Errata** An errata for table 4 on page 13.

**Table 4—Smoke-model use**

| User | Research | Regulatory | Planning | Screening |
|---|---|---|---|---|
| Local project manager | na | None[a] | | |
| (Western U.S. only) | | | NFSpuff | NFSpuff |
| (Flat or gently rolling terrain only) | | | VSMOKE-GIS | SASEM, VSMOKE |
| (Confined valley only) | | | | VALBOX |
| Regional project manager | na | None[a] | | |
| (Western U.S. only) | | | NFSpuff | NFSpuff |
| (Flat or gently rolling terrain only) | | | VSMOKE-GIS | |
| Regional systems manager | CALPUFF | None[a] | CALPUFF | |
| (Western U.S. only) | TSARS Plus | | NFSpuff, TSARS Plus | NFSpuff, TSARS Plus |
| Research scientist | CALPUFF | None[a] | CALPUFF | na |
| (Western U.S. only) | TSARS Plus | | | |

na = not available.

[a] SASEM , VSMOKE, and CALPUFF have passed EPA requirements for regulatory dispersion modeling. It is the opinion of the authors that the peculiarities of biomass burns in wildland areas have not been tested thoroughly enough for validation. Therefore, no model is recommended for regulatory applications at this time.

## Abstract

**Breyfogle, Steve; Ferguson, Sue A. 1996.** User assessment of smoke-dispersion models for wildland biomass burning. Gen. Tech. Rep. PNW-GTR-379. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 30 p.

Several smoke-dispersion models, which currently are available for modeling smoke from biomass burns, were evaluated for ease of use, availability of input data, and output data format. The input and output components of all models are listed, and differences in model physics are discussed. Each model was installed and run on a personal computer with a simple-case example. The steps required to obtain meaningful output for each model are described. Because validation data for wildland biomass burns were unavailable at the time of this assessment, recommending the use of one model over another was not possible. Limiting features of the source-strength component available for each model, however, suggest that dispersion models will not validate properly until models of source strength in biomass burns improve. Without validation data, preliminary recommendations are based on the style of user, user interfaces, output format, and available model components. Suggestions are made for which model that a local project, regional project, regional systems manager, or research scientist might select for research, regulatory, planning, and screening purposes.



Keywords: Smoke, dispersion, models, fire, prescribed fire, emissions.

## Introduction

Smoke-dispersion models are becoming increasingly valuable tools in smoke management, especially for screening and planning. Unfortunately, modeling smoke emission, transport, and dispersion from wildland biomass burns is not easy. The areal extent and varied species of biomass fuels require coarse estimates and empirical calculations to determine rates of source heat and emission. In addition, many wildland biomass burns originate in complex terrain, which influences transport winds and mixing heights. This is an especially important concern for nonbuoyant or neutrally buoyant plumes that are common in smoldering fires and understory burns.

Modeling emissions from industrial stacks, on the other hand, is much more precise because source heat and emissions can be exactly known. Also, stack emissions usually are well above or away from influencing terrain and rarely go into a smoldering phase. Therefore, although many components of biomass smoke modeling can be borrowed from industrial stack models, source-strength and smoldering trajectories are unique to wildland biomass burning.

Figure 1 shows the basic elements of smoke modeling. To determine source strength, components of heat and fuel (particle and gas species composition) must be known. For simulating biomass burns, additional information is required on (1) the pattern of ignition, (2)fuel moisture by size, (3) fuel loading by size, (4) fuel distribution, and (5) local weather that influences burn rates. Heat-release and emission rates for each gas species and particle size, which are calculated from the source-strength component, go into the plume-rise calculations. To accurately model plume-rise, ambient conditions of the atmosphere (temperature, wind, and humidity) and its mixing height must be known. In biomass burning, information on the existence and extent of local valley inversions also may be required. Once the height of the plume has been calculated, its horizontal trajectory and dispersion may be determined. In many industrial stack plumes and intense biomass fires, the trajectory winds can be well above influencing terrain, and standard dispersion algorithms are adequate. For low-intensity biomass fires, however, trajectory winds often are near Earth's surface, follow slope undulations, and are affected by diurnal temperature and pressure changes. The desired result of all models is the ability to estimate particle and gas concentrations, which affect human health and alter visibility.

Several models have been adapted or specifically designed to accommodate the peculiarities of wildland biomass burning. The primary difference between dispersion models for biomass burns and those for point-source (industrial-stack) dispersion models is the ability to accept data and calculate plume rise from a buoyant source of areal emissions associated with burning biomass fuels. The following dispersion models currently are used by Federal wildland managers and were available for this assessment: SASEM (Sestak and Riebau 1988), VALBOX (Sestak and others 1989), VSMOKE (Lavdas, in press), VSMOKE-GIS,[1] NFSpuff (Harrison 1995), TSARS Plus (Hummel and Rafsnider 1995), and CALPUFF (Scire and others 1995b).

[1] VSMOKE and VSMOKE-GIS are scientifically the same, but the input and output formats are different (Personal communication. 1994. William A. Jackson, air resource specialist, U.S. Department of Agriculture, Forest Service, National Forests in North Carolina, United States Federal Courthouse Building, P.O. Box 2750, Asheville, NC 28802). The distinction may become apparent as the merits of each are discussed in the following sections.

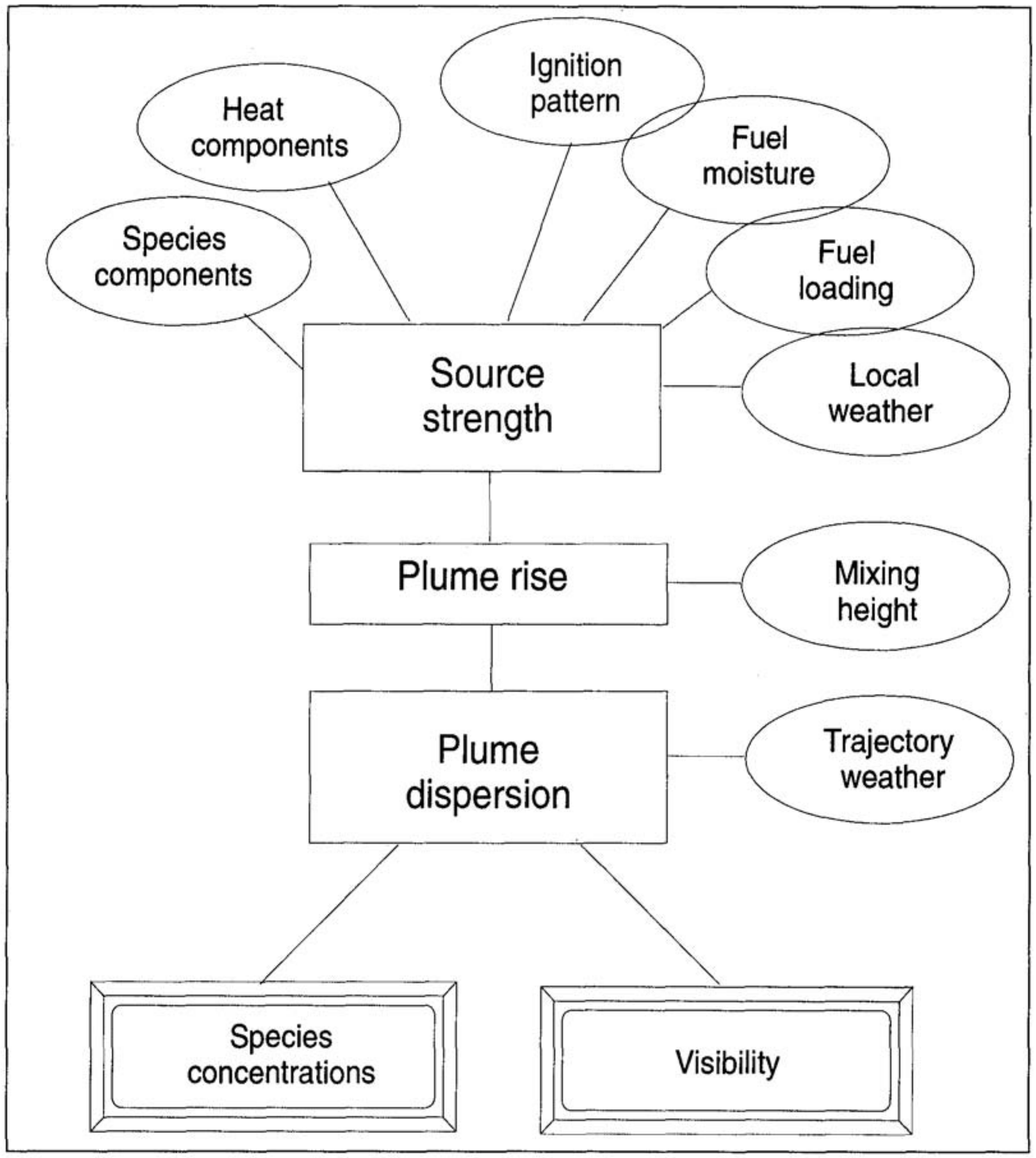


Figure 1—A schematic diagram showing the elements of smoke-dispersion models.

One reason for conducting this assessment is to help determine if the current direction in biomass smoke modeling is appropriate and what, if any, additional work is required to make the models more useful for smoke management. We, therefore, assessed the available models by evaluating their components in relation to the types of users and possible wildland smoke applications. In addition, each model was set up and run on a personal computer (PC) with a simple-case example to evaluate the ease with which meaningful output could be obtained. The following sections describe principle results, and the appendix summarizes the software capabilities of each model.

This qualitative review makes no attempt to validate smoke-dispersion models for biomass burning. Recommendations for model usage and future research are based only on subjective assessments of model performance.

## User Applications

In wildland fire management, prescribed burning carries the major emphasis for normal model use. Many users screen burns with models to help estimate possible impacts, and a few states require model output to be included in burn plans.[2] Some users play "what-if" games with the models and use output from different burn scenarios to help discuss burn options with state regulators. Other users run models under various climate and burn scenarios to help in long-range planning and assessing environmental impact. Applications to wildfire are gaining interest, especially where models can help determine the effects of wildfire versus prescribed fire.

We categorized the types of users based on their typical applications and familiarity with modeling techniques as follows:

1. **Local project managers** likely spend most of their time in the field, and thus typically cannot afford to learn or run complex computer programs. Smoke-dispersion models might be used to supplement information required to obtain burn permits or to help visualize the effects of various burning options. The models should be fast, require few input data, be easy to use, and run on a PC.

**2. Regional project managers** may be in a fuels or smoke-management role. They often come from a field background and may have slightly more computer background than a local project manager. Smoke-dispersion models may be used to supplement information in an environmental impact assessment or to evaluate tradeoffs between prescribed burning and wildfire. Regional managers also may require that models run on PCs and be relatively easy to initialize and run.

**3. Regional systems managers** may work most frequently with air-quality issues and thus have greater meteorology or computer background than regional project managers. Their job may be structured in a way that would allow more time for modeling; they may use smoke models in similar ways as regional project managers but are likely to deal with more complex issues or larger domains. They could have access and know-how to run both PCs and workstation-style computers.

[2] Personal communication. 1994. Michael L. Sestak, U.S. Geological Survey, 240 W. Prospect St., Fort Collins, CO 80526.

4. **Research scientists** should have the most knowledge of how to run and use smoke-dispersion models. They might test the sensitivities of models to various burn scenarios and model configuration options. They may be involved in interpreting model results and offering advice to managers on how to apply models appropriately for individual cases or large-scale assessments.

Wildland smoke managers traditionally categorize models based on their anticipated application. These model categories are defined as follows:

1. **Research models** are capable of modeling for many chemical components, gas and particulate concentrations, and a large radius of receptor sites and their dispersed concentrations.

2. **Regulatory models** can be used for permit approval and would be capable of showing dispersion over large geographic areas (>10,000 acres).

3. **Planning models** may apply to local or regional planning issues and could provide supporting data to help acquire burn permits for specific burns or report potential environmental impacts from various burn scenarios. These types of models should have the ability to run well in advance of an actual fire (greater than 1 year) and would be easier to use than research models.

4. **Screening models** should provide users with a "worst case" scenario to determine if alternative burn plans are warranted or if more indepth modeling is required. Therefore, screening models can be quite simple, able to capture only the worst conditions, and easy to run. Field users concerned with smaller (10- to 100-acre) prescribed burns might use a screening model to aid in visualizing what fuel and weather conditions are best suited for the burn. Managers may use these simple models to screen for the effects of large fires or multiple fires.

Currently, no model is used for making regulatory decisions about whether to burn. SASEM is used to support the obtainment of air-quality permits in several states, and some agencies are beginning to encourage the use of dispersion modeling to quantify smoke impacts in documents that report potential environmental impacts. All models were designed to supplement local expertise. Because no model has been officially validated for biomass burning,[3] regulatory use would be inappropriate at this time.

## Model Components

Components of each model are summarized in table 1. The simplest models (for example, SASEM) seem to estimate many coefficients in the component equations. These models are computationally efficient and can function on the simplest computing platforms. Complex models (for example, TSARS Plus and CALPUFF) more fully derive each equation. These models can be computationally expensive and benefit from high-speed computers. Table 2 summarizes the computer requirements for each model. Some models request readily available input data, and model results are output in formats that match regulatory figures (see table 3).

[3] Some biomass smoke trajectories have been validated against observation data (for example, Hardy and others 1993) and several models use dispersion components that have passed the Environmental Protection Agency (EPA) approval process (for example, Lavdas, in press; Sestak and Riebau 1988; Scire and others 1995b) but the peculiarities of biomass burns have not been tested thoroughly enough for validation.

**Table 1—Smoke-dispersion model components**

| Model | Spatial grid modeling | Range | No. of burns | Source strength | Surface weather | Upper weather | Plume dispersion | Air chemistry |
|---|---|---|---|---|---|---|---|---|
| SASEM | No | 100 km | 1 | EPM or internal | Single point User input | Single point User input | Straight-line trajectory (Gaussian plume) | No |
| VALBOX | No | 900 mm. feet | >1 | EPM or SASEM | Multiple points User input | None | Box | No |
| VSMOKE and VSMOKE-GIS | No | 100 km | 1 | EPM or internal or (other) | Single point User input | Single point User input | Straight-line trajectory (Gaussian plume) | No |
| NFSpuff | 8 km, 4 km, 2 km, or 1 km | 488 km[a] | [b] | EPM | Upper extrapolated Internal interpolation or slope wind approx. | NGM gridded | Variable trajectory (Gaussian puff) | No |
| TSARS Plus | 3 km, 2 km, or 1 km | 300 km[a] | 5 | EPM or SASEM | Multiple points User input NUATMOS interpolation | Multiple points User input | Variable trajectory (Gaussian puff) | No |
| CALPUFF | User defined | [a] | Unlimited | EPM or (other) | Multiple points File input CALMET interpolation or slope wind approx. | (Any gridded) Preprocessors not included | Variable trajectory (Gaussian puff) | SOx and NOx |

[a] Limited only by available domain.
[b] Limited only by number of computations. Usually can handle about 100 small fires simultaneously.

**Table 2—Computer requirements for smoke-dispersion models**

| Model | CPU[a] | Minimum disk space | Optimum disk space | Minimum memory | Optimum memory | Operating system | Monitor | Printer |
|---|---|---|---|---|---|---|---|---|
| SASEM | 286 | 140kB | 360kB | 640kB | 640kB | DOS 3.2 | Any | Dot matrix |
| VALBOX | 286 | 250kB | 360kB | 640kB | 640kB | DOS 3.2 | Any | Dot matrix |
| VSMOKE | 486DX | 160kB | 3MB | 640kB | 640kB | DOS 3.2 | Any | Any |
| VSMOKE GIS | 486DX | 1MB | 4MB | 1MB | 4MB | WIN 3.xx | VGA | Laser |
| ARCVIEW | 486DX-50MHz | >100MB | 200MB | 12MB | 16MB | WIN 3.xx | VGA | Laser |
| NFSpuff | 486DX | 60MB | 100MB | 1MB | 8MB | DOS 5.x | VGA | Any |
| TSARS Plus | 486DX-33MHz | 30MB | 100MB | 8MB | 16MB | DOS 6.x | VGA | Laser |
| CALPUFF | 486DX | 10MB | 50MB[b] | 4MB | 12MB[b] | WIN 3.xx | VGA | Dot matrix |

[a] CPU = central processing unit.
[b] Based on typical size of regional burn project.

**-Inputs and outputs of smoke-dispersion models**

| | Input | | | | Output | |
|---|---|---|---|---|---|---|
| | Site | Weather | Burn | Other | Variables | Graphic products |
| | Name<br>Owner<br>Lat./long. location | Avg. mixing height<br>"Dispersion day" max.<br>"Dispersion day" min.<br>Max. wind dir.<br>Min. wind dir.<br>Max. wind sp.<br>Min. wind sp. | Date<br>Size<br>Duration<br>Fire line intensity<br>Fuel arrangement<br>Fuel type<br>Total fuel load | Receptor sites (10)<br>Receptor distance(s)<br>Receptor direction(s) | Emission factor (g/kg)<br>Emission rate (g/s/m)<br>Total particles (tons)<br>Fuel consumed (%)<br>Fuel heat content (btu/lb)<br>percent of smoke to rise<br>Plume height<br>percent of PM10 to TSP<br>Max. TSP conc. (ug/m3)<br>Distance to max. conc.<br>Exceedence of TSP and PM10<br>"Dispersion day"<br>Visibility ranges<br>Visual range scales | |
| | Name<br>Lat./long. location<br>Number of boxes<br>Volume of each box<br>Width of each box | Day mixing height<br>Night mixing height<br>Wind dir./ time step<br>Wind sp./ time step<br>Box with wind obs. | Simulation time<br>Time step interval<br>Initial box conc.<br>SASEM burn input data<br>or EPM input data [a] | | PM10 emission /box<br>TSP emissions/box<br>TSP avg. conc./time step<br>PM10 avg. conc./time step<br>CO avg. conc./time step | |
| | Name<br>Lat./long. location | "Stability class"<br>Visibility criteria<br>Mixing height<br>Period surface obs.<br>Daylight | Date<br>Size<br>Time step interval<br>VSMOKE burn input data[b]<br>(or EPM input data)<br>(or other source strength) | | Dispersion index<br>Visibility risk index<br>Rise and depth of plume<br>Crosswind extent of plume<br>PM avg. conc./time step<br>CO avg. conc./time step | |
| IS | Name<br>X,Y UTM location<br>ArcView project | "Stability class"<br>Mixing height<br>Transport wind sp.<br>Transport wind dir. | Date<br>Size<br>VSMOKE burn input data<br>(or EPM input data)<br>(or other source strength) | Max. transport distance<br>Spacing interval<br>No. of isopleths<br>Conc./isopleth<br>Isopleth tolerance level | TSP emission rate (gm/s)<br>Total heat emission (mgw)<br>Output file for ArcView | TSP isopleth conc. overlay<br>for ArcView GIS project |

—Inputs and outputs of smoke-dispersion models (continued)

| | Input | | | | Output | |
|---|---|---|---|---|---|---|
| | Site | Weather | Burn | Other | Variables | Graphic products |
| | Name<br>Owner<br>Domain chosen graphically<br>(Internal DEM) | NGM gridded met. file<br>(Opt. steering wind) | Lat./long. location<br>No. of ignition periods<br>Duration each ignition<br>Duration between ignitions<br>EPM input data | (Western U.S.) | Heat-release rate<br>TSP-emission rate<br>Max. surface PM conc.<br>24-hr avg. surface PM conc.<br>EPM output data[c] | Time series of heat release<br>Time series of TSP emission:<br>Puff simulation with TSP conc.<br>(over topo: plan X-sec., & oblique<br>Plots of all weather data<br>Plots of topography |
| s | Name<br>Owner<br>Lat./long. domain bndry.<br>(Internal DEM) | Lat./long./elev. of ob.<br>Wind dir.<br>Wind sp.<br>Air temp.<br>Lat./long. wx. domain | Lat./long. burn domain<br>SASEM input data<br>or EPM input data | (Wyoming)<br>Receptor site locations | PM10 emission rate (g/s)<br>Emission factor (g/kg)<br>Plume height<br>PM10 conc. at all receptors | 1-hr PM10 conc. on grid<br>24-hr PM10 conc. on grid<br>Plume trajectory on contour map |
| | DEM for domain<br>Domain size<br>Domain grid spacing<br>Domain grid number<br>Lat./long. of domain center<br>Universal Trans. Mer zone | Gridded met. file<br>(MM4, NGM, etc.)<br>Precip. rates<br>Hourly surface obs.<br>Stability | Lat./long. location<br>(EPM input data)<br>(or other source strength) | | 1-hr avg. species conc. (g/m3)<br>1-hr avg. wet depos. rate<br>(g/ms/s)<br>1-hr avg. dry depos. rate (g/m2/s)<br>Relative humidity | Annual or run-length<br>files for export to<br>external graphics programs |

t data: burn date, size, harvest date, snow-off date, surface wind speed and direction, days since last rain, fuel moisture, fuel type, fuel loading by size class, duff depth, region, slope angle, and ignition method.

burn input data: smoke duration, fire duration, fuel type, total fuel loading, percentage of smoke to rise.

ut data: heat-release rate, PM2.5 emission rate, PM10 emission rate, TSP emission rate, CO emission rate, CO2 emission rate, CH4 emission rate.

## Domain

Two of the models (NFSpuff and TSARS Plus) have internal digital elevation model (DEM) data. These necessitate large hard disk storage space (50 to 100 megabytes) for computer simulations. TSARS Plus should include topography for all Western states,[4] but the version tested included only data for Wyoming. NFSpuff currently is restricted to the Western United States by its inclusive topography. CALPUFF requires users to supply their own DEM but, once supplied, makes automatic use of it.[5] Using DEM files allows easy selection of domain. The terrain data are used by each model to calculate surface trajectories. Also, output graphics are projected over topography.

VSMOKE, VSMOKE-GIS, and SASEM were designed to function anywhere over relatively flat terrains and do not require DEM data. Topography can be part of an ArcView©[7] project, however, if it is desired in output graphics for VSMOKE-GIS. VALBOX was designed to simulate smoke in a confined valley that users define by the dimensions of a box.

SASEM, VSMOKE, and VSMOKE-GIS each model one burn at a time. ArcView, however, can plot the results of multiple burns from VSMOKE-GIS. CALPUFF, NFSpuff, VALBOX, and TSARS Plus all can model multiple burns simultaneously.

Those models that consider the effects of complex terrain (NFSpuff, TSARS Plus, and CALPUFF) must simulate topographically forced surface winds. TSARS Plus and CALPUFF do this by interpolating observations to a three-dimensional grid (NUATMOS: Ross and others 1988 and CALMET: Scire and others 1995a, respectively). Both require at least one surface-wind observation and one upper air observation. NFSpuff currently estimates surface trajectories by extrapolating upper level winds. When upper level winds are decoupled from the surface or there are insufficient data, NSFpuff and CALPUFF can optionally approximate diurnally varying slope winds. Local valley inversions that affect mixing height may be simulated by TSAR Plus and CALPUFF if there are enough observational data to capture the local feature. NFSpuff and CALPUFF can imply local inversions with the diurnally varying wind options.

Another consideration in modeling winds in complex terrain is that the ingestion of surface observations does not always improve simulations. In fact, surface-wind observations may degrade simulations if observation sites are influenced by fine-scale topography or land use that is below the model resolution and not representative of the burn site, as often is the case. Until fully physical meteorological models can simulate winds and mixing heights in real time below 1 kilometer spatial resolution (still some years away), some amount of parameterization for approximating terrain and land use effects on winds will remain necessary.

[4] DEM data for all Western states should be available in 1996 (see footnote 2).

[5] Complete DEMs for the United States should be on a newly available compact disk for CALPUFF (Personal communication. 1994. Scire, Joe. Earth Tech, 196 Baker Avenue, Concord, MA 01742).

[6] In this case, the terrain, whether flat or gently rolling, should not influence the direction or speed of near-surface winds, which control smoke trajectories.

[7] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Source-strength modeling is a weak link in selecting domains and modeling dispersion patterns in regions of complex terrain. In theory, all models that rely on the USDA FS emission production model (EPM) for their source-strength calculations should be restricted by fuel type to areas with vegetation common to the Pacific Northwest. Likewise, selection of the internal, source-strength algorithm option in VSMOKE should be restricted by fuel type to areas with vegetation common to the Southeastern United States. In practice, it is possible to circumvent this restriction by choosing Northwest (or Southeast) surrogates for actual vegetation type.

Modeling dispersion patterns in complex terrain assumes a source of nonbuoyant or neutrally buoyant smoke, usually from smoldering, that follows topographically controlled, near-surface winds. Emission rates in the smoldering phase, especially the late stages of residual smoldering, are not properly accounted for in any of the available source-strength models (Ferguson and Hardy 1993, Lavdas 1982, Sestak and Riebau 1988). Therefore, even though smoke-dispersion models may be capable of simulating surface trajectories in complex terrain, by the time the burn reaches its residual smoldering phase, the source-strength models have unrealistically stopped generating smoke.

## Weather Input

Two models (NFSpuff and CALPUFF) allow input of time-varying, grid-point weather data files to represent upper air conditions. NFSpuff includes automated retrieval of preformatted nested grid model (NGM), 850 millibar data from the National Center for Environmental Prediction (NCEP) via a private vendor. If other grid-point data are desired for use with NFSpuff, then it is theoretically possible for users to acquire them and preprocess them to fit the format of NFSpuff. NFSpuff optionally allows users to input a time-invariant steering wind instead of a grid-point data file. CALPUFF can accept upper air grid-point weather data from any source, but users are required to perform all their own preprocessing to fit the input format requirements of CALPUFFCALMET.

All other models require users to manually input weather-observation data. For SASEM and VSMOKE-GIS, this is a relatively simple task because only single values for wind speed and direction at the trajectory level are necessary. TSARS Plus requires at least one user input, upper air observation and improves with multiple observations from several different heights.

CALPUFF uses hourly surface-observation data if they are preprocessed into the input file format of CALPUFF-CALMET. In TSARS Plus and CALPUFF, the more surface-observation stations there are, the more accurate the surface trajectories are modeled. VALBOX accepts a surface data record from one station for several time periods. NFSpuff currently uses no surface observations.

## Source Strength

Currently there are only three ways to estimate source strength from biomass burns for dispersion modeling: (1) EPM (Hardy and Ferguson 1994, Sandberg and Peterson 1984), (2) the internal algorithm of VSMOKE's (Lavdas 1982; Lavdas, in press), or (3) the internal algorithm of SASEM's (Sestak and Riebau 1988). Emission production model (EPM) was designed to model high-intensity slash burns in clearcut harvest residue in Washington and Oregon. It models heterogeneous fuel types and moisture regimes and considers slope and weather. Because emissions for each fuel type are empirically derived in EPM, it is not transportable to regions with different vegetation types. Regions outside of Washington and Oregon that use EPM must select Northwest fuel types that most closely match their own. The internal algorithm of VSMOKE is similar to EPM but relies more on user estimates of burn characteristics than mechanistic modeling and includes emission equations for fuel types in the Southeastern United States. The source-strength algorithms of SASEM are the simplest, assuming homogeneous fuel type and spacing of fuels.

All models include or refer to EPM as a primary source-strength component option. VALBOX and TSARS Plus optionally include the source-strength component of SASEM. CALPUFF, VSMOKE-GIS, and VSMOKE can accept data from any sourcestrength model if it is preprocessed to fit a specified file structure (CALPUFF and VSMOKE) or keyed into an entry form (VSMOKE-GIS). Currently, however, only EPM is available as an external source-strength module.

## Plume Trajectory and Dispersion

The biomass smoke-dispersion models tested for this assessment use three different standards for calculating dispersion: (1) box, (2) plume, and (3) puff. The box method assumes instantaneous mixing within a valley (VALBOX). These types of models usually are restricted to weather conditions that include low wind speeds and a strong temperature inversion that confines mixing height to within valley walls. The coordinates used to calculate box dispersions usually are fixed in space and time and thus called Eulerian coordinates. The plume method assumes that the smoke travels in a straight line under steady-state conditions (the speed and direction of particles do not change with time). SASEM, VSMOKE, and VSMOKE-GIS are plume models. The puff method simulates a continuous plume by rapidly generating a series of puffs (NFSpuff, TSARS Plus, and CALPUFF). All puff and plume models in this assessment assume that concentrations crosswind of the plume disperse in a bell-shape (Gaussian) distribution pattern. These models also use Lagrangian coordinates that essentially follow parcels as they move.

Choosing a model for biomass burn simulations is not straightforward. If meteorological data are scarce or quick estimates of "worst case" conditions are desired, then plume models (SASEM, VSMOKE, VSMOKE-GIS) may be sufficient. The straight-line trajectories even may apply in mountain regions if the plume rises well above influencing terrain. Box models (VALBOX) also are a good choice for burns confined to a valley. Puff models (NSFpuff, TSARS Plus, and CALPUFF) are designed to address all conditions, from straight-line plumes and tortuous trajectories to simple valley slosh. They require, however, abundant and realistic input data that may not always be available to run properly.

## Model Physics

A complete scientific evaluation of smoke-dispersion models is beyond the scope of this work. Principle components (plume rise, trajectory, and dispersion) of all models, however, assume functions that are consistent with standard, Environmental Protection Agency-approved, industrial stack-emission models. This was most easily discovered in user manuals citing peer-reviewed literature from which model theories and methods are based, or those manuals that include complete derivations of model-specific equations.

Primary differences in physics between the models seem to be the degree to which they fully derive equations. All models include some empirical coefficients, approximations, or parameterized equations when insufficient input data are expected or when faster computations are desired. The degree to which this is done differs among models and between components of each model.

Note that it is not clear whether fully physical calculations of plume rise and dispersion are more accurate than approximate calculations in biomass burning. There is a high degree of uncertainty in modeling source-strength of biomass burns. The burning material is scattered and highly variable in composition. Also, burn rates are time varying and influenced by ambient weather, ignition patterns, complex slope topography, and structure of surrounding vegetation. The plume rise component retains the broad uncertainty of source-strength heat-release calculations. Likewise, dispersion components retain the broad uncertainty of source-strength emission composition and release-rate calculations.

## Output Variables

Only CALPUFF includes simple atmospheric chemistry to convert $S0_2$ to $S0_4$ and $NO_x$ to $N0_3$. None of the other models include any atmospheric chemistry. Available source-strength modules for biomass burns, however, do not generate S02 or $NO_x$, so the chemistry option of CALPUFF would not apply to biomass burns at this time. Output variables of all biomass smoke models, therefore, are the result of dispersed input variables (currently from EPM or internal algorithms of SASEM or VSMOKE). Depending on the output file format and which method is used to estimate emissions, output variables of each model include one or many components of the following particles and gases:

| | |
|---|---|
| TSP | Total suspended particles |
| PM10 | Particles having diameters less than 10 microns |
| PM2.5 | Particles having diameters less than 2.5 microns |
| PM | Particulate matter (TSP, PM10, or PM2.5) |
| CO | Carbon monoxide |
| $C0^2$ | Carbon dioxide |
| $CH_4$ | Methane |

All models output concentrations of particles with distance from the source. All but VSMOKE-GIS and VALBOX output time-varying information on concentrations. The type of concentrations variously include average, total, maximum, 1 hour, and 24 hour. The specific outputs for each model are summarized in table 3.

## Output Products

VALBOX, VSMOKE, and SASEM have strictly tabular output. TSARS Plus includes internal graphical displays as well as tabular files. NFSpuff plots TSP with time in planar, cross-section, or oblique views over gridded topography. In addition, NSFpuff displays dot-contour maps of maximum and 24-hour average TSP concentrations. TSARS Plus plots 1- and 24-hour PM10 concentrations over a grid. The plume path is shown over a contour map of topography. To determine concentrations in relation to topography with TSARS Plus, it is necessary to cross-reference the trajectory-topography map with the concentration map and a table of concentration values. VSMOKE-GIS is linked to ArcView for graphically viewing isopleths of total surface PM concentrations as a geographical information system (GIS) overlay. Tabular annual or run-length output files in CALPUFF include location data so that the files can be postprocessed for export to external graphics programs.[8]

[8]A newly available compact disk for CALPUFF includes graphics simulation software (see footnote 5).

**Table 4—Smoke-model use**

| User | Research | Regulatory | Planning | Screening |
|---|---|---|---|---|
| Local project manager: | na | None[a] | | |
| Western U.S. only | | | NFSpuff | NFSpuff |
| Flat or gently rolling terrain only | | | VSMOKE-GIS | SASEM, VSMOKE |
| Confined valley only | | | | VALBOX |
| Regional project manager: | na | None[a] | NFSpuff | |
| Western U.S. only | | | VSMOKE-GIS | NFSpuff |
| Flat or gently rolling terrain only | | | | |
| Regional systems manager: | CALPUFF | None[a] | CALPUFF | |
| Western U.S. only | TSARS Plus | | NFSpuff, TSARS Plus | NFSpuff, TSARS Plus |
| Research scientist: | CALPUFF | None[a] | CALPUFF | na |
| Western U.S. only | TSARS Plus | | | |

**na = not available. a SASEM , VSMOKE, and CALPUFF have passed EPA requirements for regulatory dispersion modeling. It is the opinion of the authors that the peculiarities of biomass burns in wildland areas have not been tested thoroughly enough for validation. Therefore, no model is recommended for regulatory applications at this time.**

## Ease of Use

The appendix describes in detail the effort required to obtain a reasonable output from each model. SASEM and VALBOX were the easiest to use. Burn experience is necessary, however, to be able to select appropriate dispersion-day indices and mixing heights. VSMOKE and VSMOKE-GIS were quite easy, also, but ArcView required a steeper learning curve. Prior GIS experience would help to run VSMOKE-GIS. In addition, burn experience would help in selecting appropriate stability classes, plume rise speed, and transport wind for VSMOKE and VSMOKE-GIS. NFSpuff was very easy, prior burn experience is unnecessary to run it, and meteorological input data are readily available. TSARS Plus was moderately difficult to run, mainly because of poor error trapping[9] and intensive key punching required to enter input data. CALPUFF was designed for flexibility. Therefore, it necessarily requires time to learn about all input, run, and output options, and configure the program to fit individual modeling tasks. Once set up, however, the program runs smoothly. Locating sufficient meteorological input data for TSARS Plus and CALPUFF could become difficult, or at least time-consuming.

## Conclusions

This assessment considered ease of use, availability of input data, and format of output data. None of the models has all components necessary for any of the four categories of application (research, regulatory, planning, and screening). There are some basic characteristics of each model, however, that lend it to one or another of the other model application categories.

Based on our user-assessment of the currently available versions and a cursory understanding of user needs and abilities, we have attempted to suggest appropriate applications for each model. These are described below and summarized in table 4.

[9] A newer version has better error trapping (see footnote 2).

CALPUFF has so many alternatives for model input and such well-documented science that it can benefit most research projects. It has only two options for dispersion calculations (both Gaussian approximations), however, which may limit its ability to research all variations of biomass burning. The ability of CALPUFF to model an unlimited number of burns over an unlimited area make it ideal for large-scale planning applications. Its difficult configuration requirements may cause local and regional project managers and those with limited computer experience to avoid using CALPUFF.

TSARS Plus has similar model components to CALPUFF and thus is similarly applicable to research problems. In addition, it includes five alternatives to calculate dispersion (each Gaussian approximations) that may make it a more interesting tool than CALPUFF. Its current choice of topography restricts its use to Wyoming. In addition, the reliance on user-input data instead of file reads make it an unattractive tool to most researchers. Only five simultaneous burns are possible, and the tedious input requirements also make it a difficult tool for planning. Its cumbersome error-trapping (see footnote 9) limits its applicability to those with computer experience.

NFSpuff is fast, easy, and visually pleasing to run. Little or no prior computer or burn experience is necessary to use it. It is an ideal screening tool. Also, because it can model up to 100 burns simultaneously over a broad geographical area, it may provide a reasonable planning tool. Its current reliance on NGM data limits simulations with time-varying weather to 48-hour periods. The optional user-input steering wind and diurnal-varying surface wind, however, may allow reasonable long-period simulations for regional haze issues. Its science is not as well documented as CALPUFF or TSARS Plus, and it is limited by its choice of topography to the Western United States. It may not be appropriate, therefore, as a research tool.

VSMOKE and VSMOKE-GIS easily simulate one burn at a time. The link with ArcView makes VSMOKE-GIS a wonderful tool for quick screening or simple project planning. ArcView also allows the results of multiple burns to be viewed simultaneously. The period-by-period tabular output of VSMOKE allows detailed project planning. Both models are limited to regions of flat or gently rolling terrain. The ability of VSMOKE to use EPM[10] (or data from any other source-strength model) extends its use to relatively flat terrain in the Western United States.

VALBOX is designed for and is a reasonable choice for screening burns that are confined to simple valleys. It has a specific application and is not meant for planning or research.

SASEM is the easiest of all models to run and is perfect for anyone from a field technician on up who wants to screen individual burns. Its tabular output makes it more difficult to use as a planning tool, but because it has more output options than NFSpuff, it may be better for project planning in the Western United States as long as the domain is relatively flat.

[10] The option to use an EPM-created data file was turned off in the VSMOKE-GIS version available for this analysis. Output from EPM, or any other source-strength model, however, may be hand entered from one of the entry-form screens of VSMOKE-GIS (see footnote 1).

## Recommendations

Of the models tested, only SASEM and VALBOX have ceased development. In other models, the physics appear relatively stable, but user interfaces and output formats are changing. In addition, program bugs are being fixed. It is clear that all models would benefit from some improvement. Without a strict model comparison against a reliable set of validation data, it is impossible to determine which model is best or even the most realistic. Therefore, it would be unfair to recommend the use of one model over another based solely on this preliminary evaluation.

There are at least three critical areas, however, that necessitate additional work before any model improvements can be realized:

1. A source-strength model must be developed that can be applied to all vegetation types and burning scenarios, including wildfires and the residual phase of smoldering that is common in prescribed understory burns.

2. Smoke trajectories in complex terrain require improved methods of simulating fine-resolution slope winds.

3. Data on particle and gas concentrations in and around biomass burns must be coupled with data on ambient weather and fuel conditions to validate smoke-dispersion models. Currently, only data from lofted plumes (acquired by tower-mounted sampling packages, aircraft, and satellite) are available for validation. None of the models can be used for regulatory applications, and no model can be recommended for use over another until this type of validation occurs.

In addition to the above, improved access to available weather data would greatly improve accuracy and ease of use.

1. The USDA Forest Service and Bureau of Land Management, remote automated weather system (RAWS) data should be made more easily available from the USDA Forest Service weather information management system (WIMS) computer. The WIMS user interface should be modified to make command-line download links possible so that RAWS data from selected sites may be automatically retrieved and available for smoke-modeling input.

2. Grid-point weather data (for example, NGM and other NCEP model output) and radio-sonde observation data must be more accessible to government offices. For example, a contract with the National Weather Service could be made to transfer data twice daily to WIMS, where it would be accessed by smoke-model users. Currently, these data are purchased through private vendors.

To take advantage of the various modeling techniques and considerations of input availability, a reasonable approach for future development would be to build a fully functional modular framework (for example, Bevins and Andrews 1993). A truly modular system would be able to select appropriate components that match available input data and user output requirements.

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## Appendix

### Testing Technique

In testing these programs, the technical background and computing resources that typically may be available to a local burn boss or regional fire and smoke manager were assumed. The goal was to determine what steps were necessary and how easy it was to achieve a reasonable output. No attempt was made to perform rigorous product testing or validate the accuracy of output data.

A laptop computer was used for testing (486 DX50 MHZ, 8 megabytes system ram and a 4 MB permanent swap file). MSDOS 6.22 and WINDOWS 3.11 were the operating systems used during the test. Each program was run once or until complete model results were achieved. The models then were run through twice more to ensure that outputs were consistent. If the model was a native DOS program, it was first run in that operating system. The model was later run in a DOS Virtual Machine (VM) under Windows to see if all functions worked properly in that operating environment. Note that WINDOWS-95 was not used and there is some indication of potential incompatability.

All programs were tested with a similar set of input data to ensure some consistency. Test data were collected at a prescribed understory burn about 40 miles southwest of Bend, Oregon, at Pringle Falls Natural Research area on May 18, 1995. The surface winds during this burn had low speeds and shifting directions. The Pringle Falls data were used as input for all the programs tested because not all of the five models provided sample data sets. The Pringle Falls data also included visual observations of smoke and data from an onsite nephelometer.

### Software Model Review

Seven dispersion models, VALBOX, SASEM, VSMOKE, VSMOKE-GIS, NFSpuff, TSARS Plus, and CALPUFF were tested during summer 1995. Modelers were given a draft copy of this assessment document in September and have since fixed many of the errors and problems reported below. All but SASEM and VALBOX remain in development mode as of November 1995. Of these, NFSpuff probably was closest to being "user ready" at the time of testing. All models could add or change functions if given enough support to do so.

All models had user interactive prompting or dialog input. All the software packages received were virus free. Two of the seven models, CALPUFF and VSMOKE-GIS, offer WINDOWS-based user input, whereas NFSpuff, TSARS Plus, SASEM, VSMOKE, and VALBOX are DOS based. One of the five programs (VSMOKE-GIS) offers GIS graphic display for viewing final products. NFSpuff offers graphic display of concentrations, and TSARS Plus has tabular and graphics output. SASEM, VSMOKE, and VALBOX offer tabular data reporting.

All the models use EPM to calculate fire emissions of particulate matter (TSP, PM10, and PM2.5) and carbon gases (CO, $C0^2$, and $CH^4$). The EPM has emission factor data only for biomass species in Washington and Oregon. VSMOKE and VSMOKE-GIS have an option for an internal algorithm to calculate emissions for the Southeastern United States (see text footnote 8). In addition, SASEM has an option to use its internal algorithm to calculate emissions from homogeneous fuel types.

**SASEM [version 3.0, 1989]–**SASEM is part of the Tiered Smoke/Air Resource System (TSARS3), along with VALBOX and EPM. SASEM was designed as a screening tool for prescribed burns and was not intended for use with large wildfires. It addresses the regulatory needs for ensuring air-quality impacts under controlled burning situations for Federal lands. It has been adopted by the states of Colorado, Wyoming, New Mexico, and Arizona as the default software tool for burn planning. SASEM was not designed to integrate topographic influence, low wind speeds, or multiple fires.

The program installation is quick and has a small memory footprint while running, thereby allowing use on a wide range of processors with base memory of 512 kilobytes or greater. No problems were noted running in either native DOS or in a DOS VM under Windows. SASEM offers straightforward command-line questions for user input but does not allow file saving or retrieval of user-created datasets. Default output files are overwritten on each invocation of the program. This forces users to turn to the DOS command line if they are interested in cataloging their work. This also forces users to complete all desired combinations for fuels, site, and weather input in a single sitting. The addition of file sharing would greatly improve the program.

SASEM took less than 1 hour to run during the initial test, which indicated the ease of using the program. No errors were encountered other than disabling of the print commands in the TSARS3 batch file. This batch file must be edited if no printer is attached.[1]

SASEM is limited to 100-kilometers downwind dispersion, which is the limit of the Gaussian plume model used. Users are expected to be familiar with the "dispersion day scale," with no definitions given. Up to 10 downwind receptor sites can be defined. If SASEM emissions are used, the fire duration is defined by the user. If EPM emissions are used, duration is until the heat produced becomes less than one calorie per second.

Output products for SASEM are geared toward screening for prescribed burns and regulatory emission control. The default product is a tabular data set that combines all the possible combinations for dispersion conditions, incremented wind speed, estimated concentrations, and plume height. The estimated concentrations are listed as either no violation, or the distance range (miles) for which the primary or secondary particulate standards are exceeded. Interpretation of the results by those not familiar with the format takes some time. The receptor sites only are referenced in the optional Visibility Table data set. This summarizes the possible combinations of receptor site, "dispersion day," wind-direction range, and two different visibility scales. Again, this output requires equal time to interpret if users are not familiar with the scales involved.

[1] Although not described in the user manual, it was learned later that simply typing NUL when asked for, "Name of list device [PRN]:" will eliminate this error (Personal communication. 1994. Sestak, M.L.; Riebau, A.R. U.S. Geological Survey, 240 W. Prospect St., Fort Collins, CO 80526).

**VALBOX [version date 01/90]–**VALBOX, like SASEM, is part of TSARS3. VALBOX requires 14 steps to define a box representing the volume of a mountain valley and its weather components. Wind direction and speed also are user-defined values that can vary with time. Emissions data can be used from the other two modules or calculated from within VALBOX. VALBOX allows data file access. Users select the output time format and the duration of the burn.

VALBOX requires a steeper learning curve than SASEM on how to define the input variables. Good error handling is accomplished by repeating the current prompt if an answer has been miskeyed during the text input. For incorrect numeric responses the message, "value may be too low (or high) / do you wish to keep it Y/N?," is returned. Nowhere in the manual were minimum and maximum values listed for numeric input options or what would happen to the program results if the questionable input values were used. Minimal explanations for each question can be accessed by typing a question mark followed by a carriage return at the current command prompt. At times, users may wish for a little less brevity. All modules come loaded with default entries for each item, which can speed user input after the user becomes familiar with the programs.

The wind-input format is the poor person's "regime modeler," where inventories can be built, saved, and reused later. At each time prompt, variations in wind speed (mph) and direction (denoted by + for up valley and - for down valley) can be entered. This is tedious when entering several varying winds because, although the program seems to allow a large number of wind inputs, it allows users to edit only a small number. It would be helpful if the wind input option could use delimited text files or local weather datasets collected by remote stations. Currently, the user-input scheme is not efficient. In addition, air buoyancy and its relation to temperature and relative humidity is ignored. These factors need to be considered. Another input box for wind-speed units would save lots of conversion work.

The current user-input requirements were awkward and left little desire to continue after the first half hour, especially with runs that included shifting wind direction and that exceeded 24 hours. The initial test took 1.5 hours to produce a result. The learning curve is tedious and takes a dedicated user to become proficient. Defining the box or boxes for the model is time-consuming and would be improved by using digitized maps. The tradeoff here is that the programming effort, hardware and system requirements for digitizing would increase the scope of the model substantially.

VALBOX produces a tabular data set for TSP, with the default concentrations output at a user-specified time interval. In addition, run-time averages of concentrations may be requested. Users must run the model through two additional loops to obtain a printout of PM10 and CO concentrations. A user-definable selection for one or all of the outputs at a single command prompt would be good. The manual states that the model is for very low wind speeds. Wind speeds at Pringle Falls were often below 1 mph, which raised the, "value may be too low / do you wish to keep it Y/N?," warning during user input. This is a thoughtful reminder that few instruments can measure very low wind speeds accurately, thereby allowing users to reconsider or continue.

**VSMOKE [version 19950128] and VSMOKE-GIS [version date 04/95]**–VSMOKE was initially written to determine potential visibility reduction for motorists and is a dispersion model only. VSMOKE can be used to estimate visibility if the relative humidity is < 70 percent. VSMOKE uses a Gaussian dispersion algorithm based on industrial smoke-stack emissions. The program currently comes in two versions, DOS (VSMOKE) or a visual basic (VB) front-end (VSMOKE-GIS) that preprocesses user input for display in ArcView.

The copy received for the evaluation was the VSMOKE-GIS for Windows beta version (Jackson 1995). A draft manual was included with the software with reference to Lavdas (in press). The brevity of the manual was good. Description of some key input variables of the main GIS *Input Form* VSMOKE-GIS's, however, were missing. Others were worded so the tester had to truly test by trial and error to achieve success, which caused confusion. No onboard help was available within the program.

Initial installation of VSMOKE-GIS is quick and easy. A VSMOKE-GIS group is created automatically for Program Manager in Windows with an internal VSMOKEGIS icon. When fully loaded, VSMOKE-GIS uses about 190 kilobites of the available system resources.

Although the geographical user interface (GUI) is attractive, use of the tab key, instead of the mouse, to move between input boxes leads users on a trail of confusion. The program was sensitive to user input, and it crashed or trapped an error issuing an alert box) and then terminated the program on seven different occasions. Users need seven steps to calculate downwind PM concentrations for prescribed fires. The initial time required to successfully complete all form options and save the appropriate files for ArcView was quick and easy. It required about 4 hours, however, to resolve problems of loading and running ArcView. Weather-input options include one single user-defined wind direction for the duration of the dispersion run, a transport wind speed, mixing height, and atmospheric stability class. Check boxes exist for the period of daylight and the expected plume-rise speed (a qualitative value based on the user's guess). Site data includes universal transverse mercator (UTM) grid coordinates, fire size, and background concentration level.

Total emissions are not calculated in VSMOKE-GIS. Instead total source emission rate for PM (grams per second) and total sensible heat emissions (megawatts) were calculated by the program from the *Calculations* menu option. This form allows users to choose fuel type, loading, smoke duration, and fire length. To finish this form, choose the *Calculate* button and the *Use Answer* button; the results are entered into the main *GIS Input Form.* It is important to remember to enter the size of the fire (acres) on the main input form before using the *Calculations* module. If not, the program returns a <"Type Mismatch Error'> message and terminates. [3]

[2] A newer version has fixed this error (Jackson, see text footnote 1).

[3] A newer version has changed this to allow users a second chance to input fire size (Jackson, see text footnote 1).

Fuel moisture is not directly put into the program. Instead it is implied by the user input value of proportion of emission subject to plume rise. This also allows for a calculated departure from the industrial stack emissions to determine what percentage of total smoke will rise. Full scale for the proportion of emissions subject to plume rise is -1 to +1, with values less than 0 for low fuel moisture (-0.75 default) and anticipated heavy smolder, and values greater than 0 for fast-burning fires, that is, low fuel moisture (0.5 to 0.9 recommended).

Output options include up to 100[4] user-selectable isopleths for graded PM concentrations (micrograms per cubic meter) available by clicking on the *Set spacing interval* button in the *GIS Input Form.* This loads the *DownWind Interval form*. At first this form is tricky to use, as some objects are controls and some are not. The instructions in the manual for this could be better. Also, you can assign a tolerance level for each PM concentration, which can speed computation for the isopleths. The downwind calculations have a maximum distance of 100 kilometers.

Once users are familiar with ArcView and the *GIS Input Form,* the strength of this model is realized in the amount of burn scenarios that can be developed and displayed efficiently. VSMOKE-GIS currently does not supply terrain data and has been developed for use in gentle, rolling terrain. A single steering wind is constant for the concentration trajectory. The difference in using three and seven isopleths slows the computer somewhat. A valid consideration in this software suite is the learning curve needed to develop new projects. In some ways, this may limit the number of users fully using this application. Because ArcView uses UTM grid system, it would be handy if VSMOKE-GIS contained a module to convert latitude and longitude to UTM.

A tradeoff does exist in hardware overhead for use of ArcView, and requires these hardware options:

- At least a 486DX processor
- WINDOWS 3.0 or greater
- 12000 kilobytes of virtual memory
- Accelerated Windows-type graphics card (advised)
- Config.sys needs to have files=65
- compact disk drive
- UTM easting coordinate system

The weaknesses centered around the user-interface of VSMOKE-GIS. If a GUI interface is used, all effort should be made to make it as simple as possible for users to achieve results, otherwise the purpose is defeated. A novice user would potentially become frustrated with the input form. Items that added to this problem were:

- Error trapping that ends in program termination, with a <"Type mismatch error"> message being the most common[5]

4 A newer version has changed this to 10 isopleths (Jackson, see text footnote 1).

5 A newer version has fixed this error (Jackson, see text footnote 1).

Standard Windows conventions were not followed, especially with default command keystrokes for standard commands (for example, alt+F / O for file open) and mouse clicks or double clicks

Alert boxes were uninformative, which did nothing to help user before program termination

**NFSpuff [Version 1.16x, 7/14/95]–**NFSpuff uses three modules for user input:

- *Emissions* (Modified USFS EPM)
- *Weather* (For obtaining and displaying radiosonde observation data and 700 mb and 850 mb data from NGM)
- *Trajectories* (Defines model domain and topographic grid resolution, assigns emission and weather data files, and plots simulated plume and TSP concentrations)

The manual is well thought-out, and provides useful information in a concise guide orientated towards the end user. The initial part of the manual guides users-through the major functions of the program. More technical information about the scope of the software is in the appendices or available request from the developer. No printer support is offered in the program; rather a screen capture utility must be used to produce hard copy graphics output.

Full installation takes 44 megabytes of hard disk space; increased terrain files are the main factor for increased hard drive footprint. The install program is simple and offered no problems. The useability of the accompanying manual is equal to its predecessors. All portions of the software have no problem running in native DOS or in a DOS VM from Windows.

The user-input scheme is menu driven with each module treated separately. Once a module is selected, a list of input questions is presented. If out-of-range values are entered, a help screen appears defining the variable limits along with a prompt for entering a legal value. This provides a "no questions asked" format and good error trapping. All selections in this program are keyboard driven; mice are not supported. The software allows saving and editing of all module data by unique names. Formatted output files for maximum concentrations are overwritten on each run from the *Trajectories* module.

The *Trajectories* module allows users to define the modeling domain by latitude and longitude of its northwest corner through a graphic interface. Users can select 1, 2, 4, or 8 kilometer grid resolutions for the plotting area, depending on the domain size. This selection process requires practice, but is intuitive and efficient.

The finished planar view terrain map shows burn sites and population centers as different sized red circles (towns with less than 1,000 population are not shown). The map also shows roads, rivers, lakes, and railroads (all user display options). NFSpuff offers terrain maps for the entire Western United States and parts of Canada. At this point, the capabilities of NFSpuff may be outstripping EPM. Forest types for areas outside Washington and Oregon are not currently cataloged in EPM lookup tables for fuels. The generated maps can be saved for future use. Once these steps are completed, users can recall any of the separate data files from within the *Trajectories* module.

Output also is generated from the *Trajectories* module by choosing a terrain map, emission files, and weather file (NGM) or optional user-input steering wind. Other options from the *Trajectories Operation Menu* include selecting optional surface-wind algorithms. Surface winds either can be extrapolated from NGM 850 millibar winds and adjusted for conservation of mass around the topography, or as "thermal slosh" by initiating a new algorithm. Use of the "thermal slosh" defaults to follow a simple sinusoid, with a maximum up-valley wind at 2 p.m. and down-valley at 2 a.m. The program analyzes the topographic map and defines the long axis of the valley. The extrapolated winds are based on thermal gradients adjusted for the terrain. Presently, importing of real surface-wind data is not supported.

Also in the *Trajectories Operations Menu* is an option to display or revise dispersion coefficients. This primarily is geared towards the advanced user and allows considerably more manipulation of the system. User-edited variables include:

- Surface temperature
- Temperature-lapse rate
- Puff-emission interval
- Eddy diffusivity (hotter fires >= 50, cool fires <= 50)
- Plume-entrainment coefficient

Another option is the choice between cumulative and transient graphic displays. The former is the default display that allows the time-lapse exposure of plumes through their rise and decay process. The transient mode traces single puffs about the screen, and can help visualize the trajectory of individual puff particles. Note that this mode erases the map pattern as its trajectory is plotted over the topography.

Final products include a real-time graphic display of color-coded concentration levels in simulated animation overlaying the terrain map. During the model run, users can pause the display or request cross-sectional plots of the plume heights. Users define the azimuth for these cross sections. An oblique terrain perspective plot also is available from this menu, which once again simulates the dispersion of color-coded puffs.

A plot of maximum and 24-hour average concentrations is generated over topography when you exit the main puff simulation. The data for these two concentrations are written to individual files (*mapname*.max and *mapname*.avg). If users are interested in cataloging these files, it is necessary to rename them, as the files are overwritten if the map is reused for different burn scenarios.

The user interface, graphic output, and speed of NFSpuff make it pleasurable to use. The ease of achieving results and the speed of graphic displays are very good.

**TSARS Plus [version 1, 7/24/95]–**TSARS Plus is the next generation of TSARS3 and is a DOS-based application. SASEM and EPM are the only code modules brought forward to this new software. All other supporting modules are new. Both formatted reports and graphic displays are user-output options. The software now offers terrain support for generating the wind file and contour map. The version received for testing had only the terrain maps for Wyoming included (see text footnote 4).

The installation process for the six system disks program runs well if you use the setup defaults. Changes to these defaults will crash the install program unless users edit *the Ezi.cfg* file on disk one of the set. Other install characteristics are:

- Traps wrong disk
- Tries to change config.sys to files = 99, buffers =20
- Wants to add \tsarsp to your path
- Copies *tsarsp.bat* to the boot drive of your machine

These hardware and software requirements (listed in the manual) are recommended:

- 11 to 20 megabyte disk space for installation
- 486dx 50 MHZ processor (33 MHZ will do in a pinch)
- 8 megabytes RAM
- A burn project can take 3 megabytes of space
- terrain maps can take 7 megabytes
- The program runs in 3 megabytes
- *Share.exe* cannot be used simultaneously with TSARS Plus
- The program requires MSDOS 6.x or greater (recommended due to its Multiple config.sys and autoexec.bat options)
- Cannot be run in a DOS VM under Windows
- A laser printer required for tabular reports and graphics
- A dot matrix printer for tabular reports only
- It is not network compatible

Because this is a file-intensive program, the manual says to always use *File / Quit* to exit the program. If users do not use *File /Quit* to exit, the indexed database filing system will not write all open files properly to disk, leaving users with lost clusters, orphaned files, and damaged indexes. Users should see a message, "Foxpro normal shutdown," when exiting from the program in this manner (we never did).

A manual, draft 7.95, was included with the software. It describes in adequate detail the steps necessary for completing a burn project. Tips are highlighted in bold type, and are appreciated. Examples of output products are given in an appendix of the manual.

A modular template and building block system is used to create the essential data necessary to define a burn project. All the template data are stored and are reusable or can be modified for use in other burn projects. Users must follow the *TSARS Plus Steps to Success* flowchart to expect results from the program. This can be displayed on screen and is also in the manual. Predefining of all components of step 1 are necessary before defining a burn project. All the templates and building block functions are found under the *Database* menu option. The software uses data-input forms, which are then saved as database records. As this inventory of information grows, users are allowed to query the database for specific records with the *Find* function for all the template categories. This is a good option that can speed access to desired data.

Because all pieces of step 1 share latitude and longitude coordinates, the user needs to know the size and latitude and longitude coordinates of the final burn project to adequately assign receptors and all other template groups.

The first steps require setting up fire and receptor definitions, which are straightforward processes. If EPM is used, TSARS Plus uses the heat release rates of EPM to calculate plume rise. If the source strength of SASEM is used, TSARS Plus uses internally calculated plume rise of SASEM.

Next, users need to define the meteorological stations and associated wind data for those stations; the number of user-created stations is unlimited. Stations are defined by latitude, longitude, and elevation. Basic data for the stations include surface wind speed, direction, stability class, mixing height, and air temperature. Once these are assigned for a particular date and time, users have the option to assign upper air observations for that same time period. Users will find later that multiple levels of upper air data are required. The manual does not explain this, which can result in having to backtrack to complete the projects

The last requirement for building templates is defining the wind files. This requires users to define the latitude and longitude coordinates of the northwest corner of the project and three user-input scenarios:

1. Domain size. (100, 200, or 300 square kilometers)

2. Met station. (Selection of meteorological stations from a list of those that lie within the defined domain)

3. Met station data. (Selection of data by name, date, and time)

Completion of these steps produces a *Generating Wind Field File* dialog box. Three-dimensional wind fields are generated by the NUATMOS meteorological model. Meanwhile, the terrain map is created from a subset of TAPAS (Fox and others 1983) terrain data. The wind field output takes about 3 to 4 minutes of processing time to complete, if the terrain maps need to be created. If a terrain map already exists for the selected domain, it is recalled, and processing time is reduced.

Defining the burn project is the last requirement before receiving tabular reports or graphic display information. This requires 12 user inputs with various subforms involved. Multiple fires in one domain are allowed, but you have to edit the fire definition subform before completion. Upon satisfying the burn project definition requirements, a gridded map of Wyoming was drawn on the screen showing the defined domain and the major cities. If not satisfied with the current definition, the user has the option to delete the current burn project and start over again or accept it. It would seem more logical to initially set up the domain on the map rather than wait until the final verification to show it.

[6] A newer version has fixed this omission from the manual (see footnote 1).

The graphics representation of the output data is a new and important feature for TSARS Plus. CITPUFF (Ross and others 1987), the plume dispersion module of TSARS Plus, generates three-dimensional models of puff trajectories and dispersion by using Lagrangian puff and Gaussian dispersion techniques. On each applicable map or grid product, these key letters are seen:

"F" (fire location)

"R" (valid receptors)

"H" (the point of highest concentration)

After each graph is drawn on the screen, users have the option to toggle the print screen key to receive a printed copy (laser printers only). Three options for graphics exist:

1. Concentrations on the Grid with Receptors. (Shows concentration isopleths and the legend informs users of contour interval (micrograms per cubic meter), the isopleths are overlaid on a grid)

2. Display Contour Map. (Offers a choice of projects from the burn project inventory and gives a speedy plot of topography with overlay of named fire (F) and receptor (R) sites within that domain)

3. Puffs on Terrain Contour. (Shows the contour map overlain by concentric puffs, which follow the prevailing wind trajectory and emulate lateral dispersion, where the cross (+) at the bottom of each circle represents the point concentration levels given in the tabular report at that time step)

After completing the burn-project development, the maps are automatically created and displayed. Output data are saved in the database for future access. The first display is of the contour map of the domain, which takes about 30 to 60 seconds to draw. The next graph is the *Concentration on the Grid* with Receptors, followed by *Puffs on* Terrain Contour simulation, which took 5 to 10 minutes to compute and display.[7]

The graphics provide good information. Depending on the default values assigned in the burn project, users can step through graphic pages for each time period selected. If 24-hour averages were selected, one of each map-type is generated. If 1-hour averages were used, users can view each time-step for the duration of the run. Use of the multiple time steps feature produced such halting screen redraws for both the *Concentration on the Grid with* Receptors and *Puffs on Terrain Contour* displays that there was an impression that the program had locked up, even though it was still working. The manual states that a 486 DX 50 MHZ will give optimal performance. Testing, however, emphasized that a Pentium or DX4 100 MHZ processor would be a better choice.

7 If 1-hour averaging is selected, the first-hour Puffs on Terrain Contour is displayed. If 24-hour averaging is selected, the concentration contour is displayed for the first 24-hour period (Sestak and Riebau, see footnote 6).

When the message, "use Print Scrn to print," displays, the current graphics page is completely redrawn. If users press any key other than *enter, carriage return,* or *Print Screen,* the characters are typed on the screen over the graphics. It also was found that when in the *Assign Met Station to Wind Field File* menu, if users hit the *ESC* key instead of mousing to close, the current screen scrolls partially off the screen. This effectively locks up the program and keyboard. This same scenario happens in *Output Puffs on Terrain Contour* by hitting *ESC* instead of *carriage return.*

The TSARS Plus package has many powerful features, and is set up to allow users to store and retrieve a great amount of scenario data for prescribed burning. The option for either tabular or graphic outputs is a large step towards easier interpretation of data. Although the sample files worked fine to become acquainted with the software, defining a new burn project was not as easy. Most sessions with this program resulted in unrecoverable errors. All errors encountered were major in the sense that after an initial warning message, any key press would bring the full error message and program termination. Heeding the instruction, "always exit program with File/Quit," users are unaware if all the files have been saved properly during the error-trapping event. The program does offer a utility to rebuild damaged database files and their indexes. At one point, even this function failed, making it necessary to reinstall the software.

External weather data files cannot be imported into the program because the model developers have found no source readily accessible to field personnel and project managers. This means that the use of real-time weather products by the program is cumbersome. Instead, a set of data-entry forms exist in the *Wind Field Setup /Assign Met Station Data* option, under the *Database menu,* where users are responsible for hand-keying this information into the database. The program does not seem to facilitate quick changes in wind data, [9] to play many "what-if" scenarios in a short time span. Users are forced to restructure multiple elements in the template system, namely meteorological stations and their data, and recalculate concentrations and wind-field generation to receive graphics or tabular report output.

The program seems too geographically dependent and limited by the stringent latitude and longitude of program requirements for most template data. For each run, users must input the location of all meteorological, fire, and receptor sites before knowing whether or not the sites fit into the domain. Because TSARS Plus requires at least one upper air observation, surface-wind approximations improve with a greater number of surface observations, and receptor locations are crucial for each simulation, it would help to know a priori if the sites all fit into the domain or not. The program matches the domain with latitude and longitude locations automatically after all site locations are entered. This is a difficult task for users, because domains are defined by the latitude and longitude of one corner, then a size in kilometers. If the

[8] A newer version has fixed this error (Sestak and Riebau, see footnote 6).

[9] Apparently it is possible to easily change most of the meteorological data, but how to do so is not intuitive (Sestak and Riebau, see footnote 2).

sites do not fit into the domain, and users need them to fit, all must be reentered. In the current program flow, the process of constructing templates seems overly complex and can leave users wondering which piece of information is not correctly listing the latitude and longitude for the project. This results in a fair amount of backtracking to correct user errors instead of getting the results.

Tolerances for location definitions of meteorological stations seem equally restrictive when, for example, the grid is misaligned. The manual makes no mention of tolerance for the reuse of existing terrain maps. Do these domain grids need to match precisely, or can they overlap a certain amount and still be reused? Also, if you assign a meteorological station with proper latitude and longitude, but a bogus elevation, what does this do to the validity of wind-field or burn-project definition?

**CALPUFF [version 3.0, 07/95]**–CALPUFF is a multilayer, multispecies, nonsteadystate Gaussian puff dispersion model containing modules for complex terrain effects, overwater transport, coastal interactive effects, building downwash, wet and dry removal, and simple chemical transformation. Project development is being funded by regulatory agencies and industry in the United States and Australia. This program is capable of serious modeling for air transport of particulate matter over time and space, and it uses gridded domains with multiple vertical layers.

Installation of the software offered no problems with a group created in Program Manager of Windows that contains CALPUFF and CALMET icons and a “help” icon for each. The help system gives an informative program overview, defines limits for any input variable, and offers detailed technical program details. Installation of this version of the CALPUFF group uses about 8 megabytes of disk space.

Both CALMET and CALPUFF currently have Windows-VB input programs. The user-interface of CALPUFF has been developed to allow users an alternative project development environment to editing *filename.INP* - the run control file that controls all file input and output, modeled species, and terrain parameters. This is an ASCII text file with which users needs to become familiar. Both CALMET and CALPUFF exit to a DOS extender shell to execute their respective Fortran executable files. The user-interface goes one step further in trapping potential input errors by rule checking the current control file [?.INP] before running the Fortran executable files. This routine will display the errors in a table, which allows direct access to the input form and correction of the error. The software features good development and error trapping, and follows standard Windows conventions.

CALMET is a diagnostic wind-file generator capable of micrometeorological modeling for overland and water boundary conditions, among other things. It also came with a Windows user-interface written in VB. CALMET needs several preprocessors that format various National Climate Data Center (NCDC) data (for example, CSUMM, TD3240, and MM4). The CALMET version 3.0 did not come with the six weather preprocessors that are listed in the CALMET program flow diagram.[10] At this time, users of CALMET may need to create their own preprocessors for meteorological data not currently supported.

[10] Weather preprocessors should be on a newly available compact disk for CALPUFF (Scire, see text footnote 5).

CALPOST is included with CALPUFF and is a DOS-based executable.11 CALPOST is a required step to format output files so they can be exported to external graphics programs. It creates time-averaged concentrations and deposition fluxes predicted by CALPUFF. CALPOST also is capable of computing visibility impacts. A batch file is included, which allows users to assign the current *calpost.INP* file and input data *(model.dat) as* command-line trailers. References to CALPOST can be found in the user manual.

The raw input file of EPM data for CALPUFF is *Baemarb.dat* (buoyant source emissions file with arbitrarily varying emissions). The manual states that an unnamed preprocessor is included with version 3.0 to prepare EPM output for CALPUFF. No version of EPM was included with the program. For many of the input files for CALPUFF, a sample data file is included in the header and variable description section of the manual. For others, such as *Volem.dat* and *Baemarb.dat,* no sample file is offered. Without a biomass source-strength module (for example, EPM) no results could be produced with CALPUFF for biomass burns.

Another program is said to round out the CALPUFF suite. This is CALGRID, an Eulerian photochemical transport and dispersion model, which supplies subgrid analysis for complex terrain. Output format and file structure seem to be currently unassigned in the manual. CALGRID was not supplied with version 3.0.

The manuals (one for each module), are extensive and, because of the complexity of the program, need to be used. They are more scientific reports, however, than "how-to" user manuals. It required over 2 hours of reading to become familiar with the features and layout of the program. Nowhere in the manual, or the onboard help, is there a quick and dirty explanation of how to jump into the program and obtain results.
In short, CALPUFF is a program written by scientists for scientists that has not been developed for use by field people. The program expects a lot of background knowledge on the part of the end user.

Although CALPUFF offers a rich set of features for regional air management, it seems to remain in the developmental stages. It also seems that each release of CALPUFF adds another finished segment of the entire package. Currently, the use of final output products is left to the imagination of the user. CALPOST does output data in a format suitable for import into other statistical or graphics packages for final interpretation.

[11] A newer version of CALPOST has its own Windows interface (Scire, see text footnote 5).



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**Breyfogle, Steve; Ferguson, Sue A. 1996.** User assessment of smoke-dispersion models for wildland biomass burning. Gen. Tech. Rep. PNW-GTR-379. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 30 p.

Several smoke-dispersion models, which currently are available for modeling smoke from biomass burns, were evaluated for ease of use, availability of input data, and output data format. The input and output components of all models are listed, and differences in model physics are discussed. Each model was installed and run on a personal computer with a simple-case example. The steps required to obtain meaningful output for each model are described. Because validation data for wildland biomass burns were unavailable at the time of this assessment, recommending the use of one model over another was not possible. Limiting features of the source-strength component available for each model, however, suggest that dispersion models will not validate properly until models of source strength in biomass burns improve. Without validation data, preliminary recommendations are based on the style of user, user interfaces, output format, and available model components. Suggestions are made for which model that a local project, regional project, regional systems manager, or research scientist might select for research, regulatory, planning, and screening purposes.

Keywords: Smoke, dispersion, models, fire, prescribed fire, emissions.



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